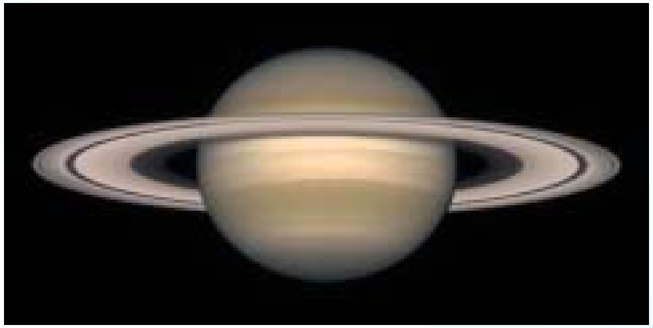
ARWIN the interferometer – technology and prospects

Malcolm Fridlund
ESA

Status exo-planet search



Stars (Solar type = F, G, K) observed: + 3000

Planets detected: > 120

Radial velocity measurement precision

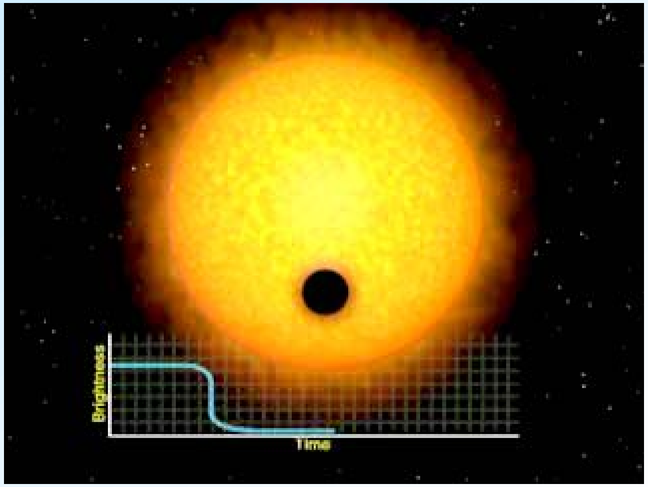
- Current precision ~ 3 m/s and shrinking
- 1-2 m/s intrinsic limit? ➔Saturn mass planets@ 1AU
- Earth in habitable zone requires 0.1 m/s
- High eccentricity
- 1 per month

Summary:

- Very large planets detected
- Unexpected orbital mechanics encountered
- Nothing similar to our solar system found
- Radial velocity can not detect earth-like planets

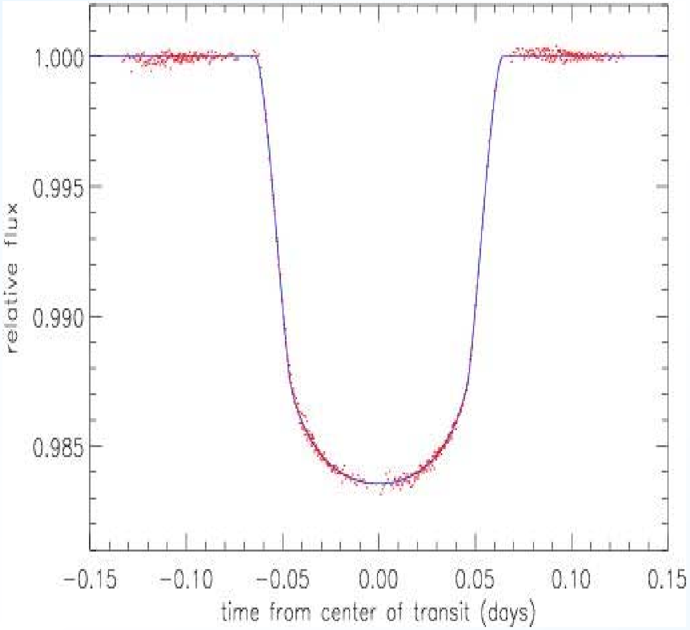
Corot, Kepler and Eddington(?) will detect (?) rocky planets and maybe (?) give η_{Earth}

Exo-planets exist



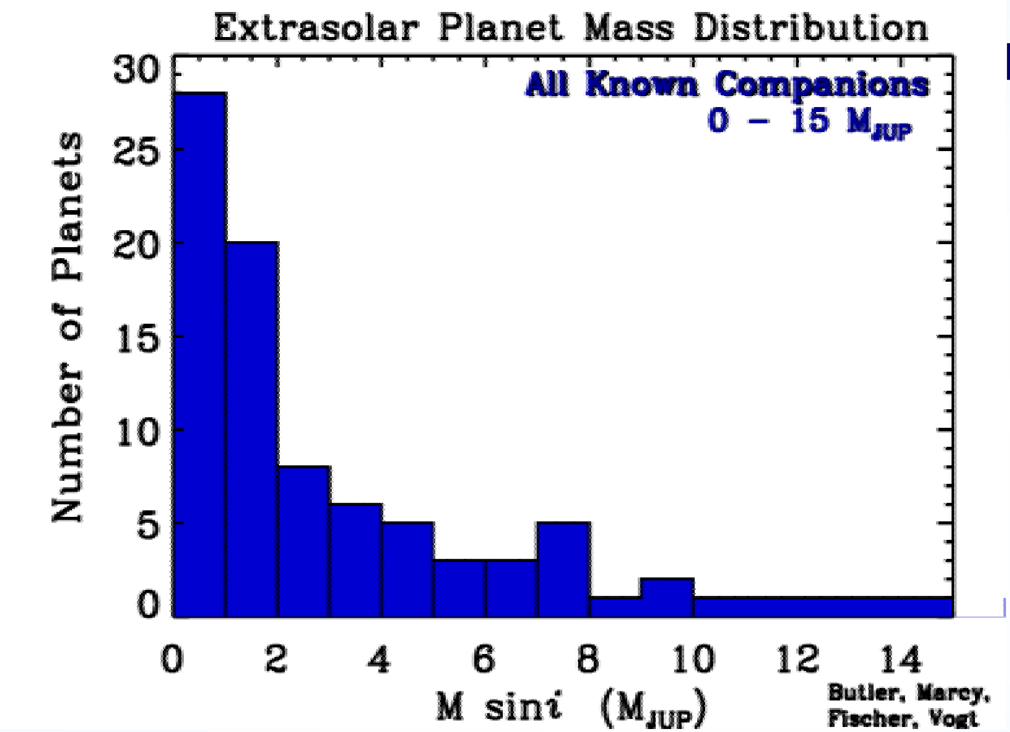
Occultation of star by planet:

- Probability 1% of occultation cone sweeping across Earth
- One predicted case (compare > 120 RV exoplanets)



- Planet orbiting HD209458
- P = 3.5 days
- m = 0.7 M_{jup}
- R_p = 1.4 R_{jup} ➔ No Core!
- Migration < 10^7 years
- Detection of sodium in absorption spectrum
- Gravitational lensing: 3 planets detected
- HST FGS: 1 planet detected

Search For Exo-planets Results



Exo-planet mass distribution.

Proportional to 1 / M sin(i) ?

Lowest minimum mass = 0.12 M_{jup} = 40 M_{earth}

"Brown Dwarf desert"

Models incorrect or incompatible

TE's are major topic for space agencies

In NASA's ORIGINS program

In ESA's Cosmic Vision Program

- The search for, studying of and characterisation of Terrestrial Exoplanets (TE's)

-The habitability of these worlds

-The search for biological activity on any TE found

Major topic for space agencies

In ESA's Cosmic Vision Program

- **COROT, Herschel**
- **GENIE ➔ Ground based European Nulling Experiment**
    - **With ESO/VLTI**
- **Eddington (?)**
- **GAIA**

➔ Darwin

Corot

Eddington

GAIA

Herschel

Program has 3 Top level requirements

“What is the uniqueness of our own Earth?”

- The searching for, study & characterization (incl. Atmospheres) of Terrestrial Exoplanets (TE’s)

“Are we (lifeforms) alone?”

- The habitability of these worlds, search for biomarkers

“What is our future?”

- The evolution of these worlds

Definitions

Terrestrial planet: Minimum 0.5 R_{Earth}, Maximum ~ 2 R_{Earth}, T_{eff} ~260 – 373 K, ρ > 3g cm^{-3}

Giant planet: M > ~ 15 M_{earth}

HZ ~ Liquid water on surface

HZ ~ 0.7AU to ~> 1.5AU

Continuous HZ 0.9AU-1.1AU

Prevalence:

1. **Number of TE's per star (solar type) >3 in our system**
2. **Fraction of stars (solar type) with TE's (η_{Earth}) $^{-1}$?**

Mission requirements

A TE mission:

Must be able to detect and discern between all types of TE's (Venus, Earth, Mars)

Must search for and study planets found around an as wide range of types of stars as possible (spectra, metallicity, evolutionary phase)

Should be able to observe an as wide as possible range of parameters

Must study habitability in a large enough sample in order to establish timelines, conditions and key points in formation and evolution of life

Need to be able to detect key signatures in any planetary atmosphere indicating habitability

Need to be able to detect bio-markers

TE-SAT reconfirms scientific goals of Darwin

Goal: Find Earth-like planets around nearby stars of Solar type. Characterise them, also as what concerns their ability to host "life as we know it"

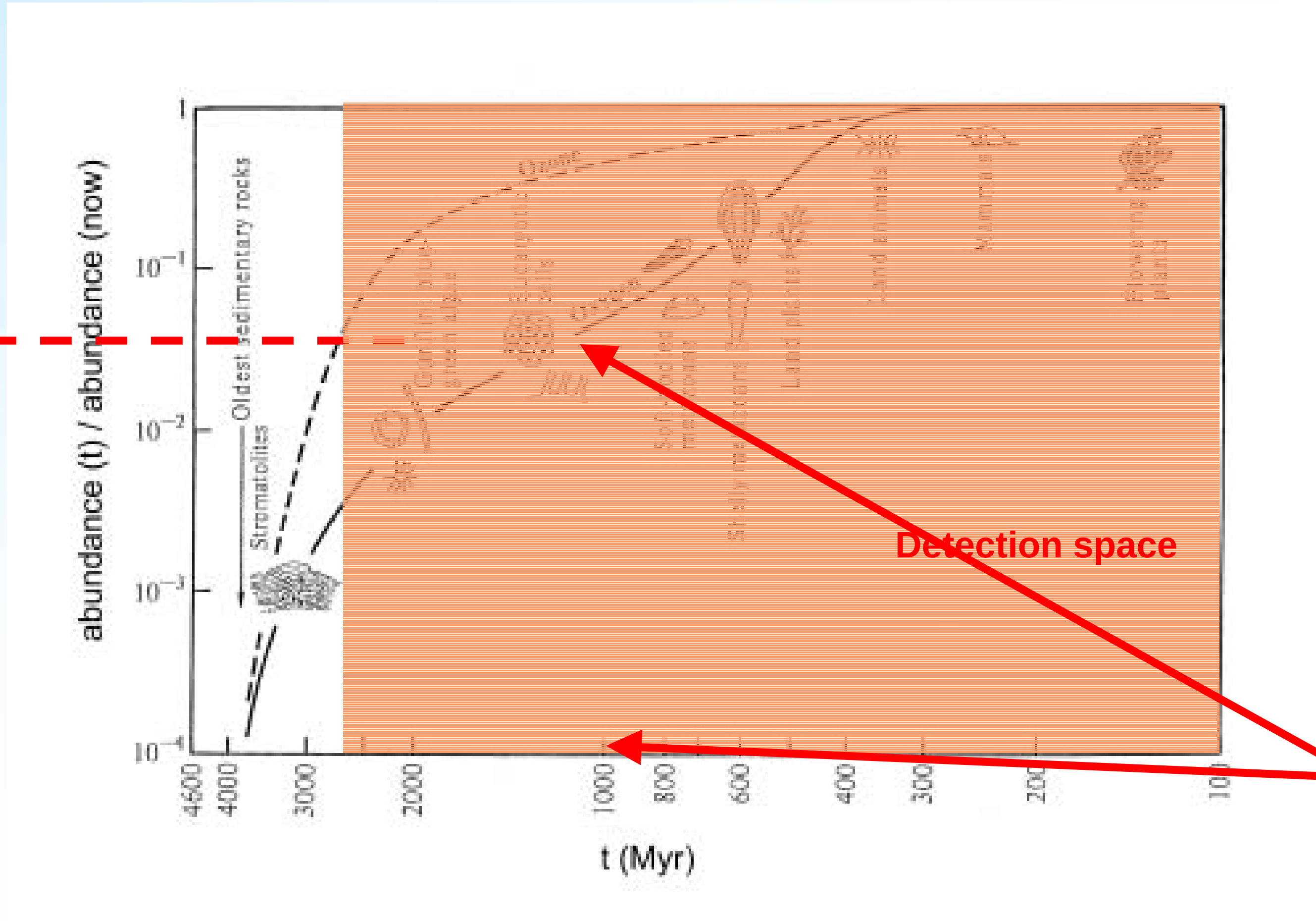
Primary objective: Detect and study Earth-like planets in the habitable zone around a large enough (translating into 50-100 stars searched in first 2 years of mission) sample of Solar type stars to be statistically significant
➔ while covering different evolutionary phases and physical

DARWIN requires a large enough stellar sample of the solar type
➔Input catalogue contains 285 stars to 75 ly

Ozone / Oxygen

IR low spect resolution

O_3 detection limit



Visual, high spect resolution !

O_3 allows detection of life in early phases

O_2 would allow a better determination of evolution stage.

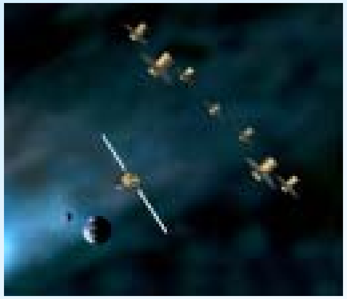
Main Requirements

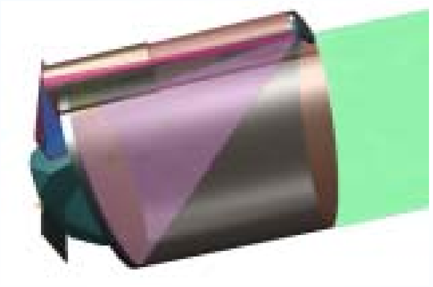
Red numbers are desirables

	Specification	Comment
Stellar types	F, G + some K & M stars	Solar type star defined as F5 to K9
Stellar distance	25 pc	Nearest star to earth is 1 pc away
Number of stars (5yrs)	150 (285)	***Negative result must be meaningful*.**
Planet radius	1.0 R_{earth}(1/2Earth surface)	Max. radius terrestrial planet ~ 2 R_{earth}
Spectral range	6 – 18 μm	Covers key absorption lines
Spectral resolution	20 (50)	50 for CH_4 (TBC)
Number of revisits	3 (TBC)	Confidence level 90% of detection

	Derived requirements	Comment
Detection phase	2 yrs (+2)	Allows follow > 80 stars
Spectroscopy phase	3 yrs (+3)	Allows > 15 planet spectras to be taken

2 ways to go: Coronography or Nulling Interferometry





Interferometer:

1. **Must be free-flyer if realizing full potential**
2. **Must be more than 2 elements to be efficient (transmission pattern)**
3. **Unit telescopes must be large (> 2m class)**
4. **Open ended ➔ extended mission + flexible mission performance**
5. **Operating in IR (6μm-18μm) allows to have relaxed optical requirements**
6. **Spectral resolution ~ 20 ➔ delivers science**

Coronograph:

1. **Need to operate in visual λ = 0.5 – 1.06μm**
2. **Wave fronts ~0.03 Å rms**
3. **Mirror need to be large**
4. **Not open ended ➔ No flexibility**
5. **Leaves no heritage**

Nulling IR interferometry is ESA's chosen technology for Darwin

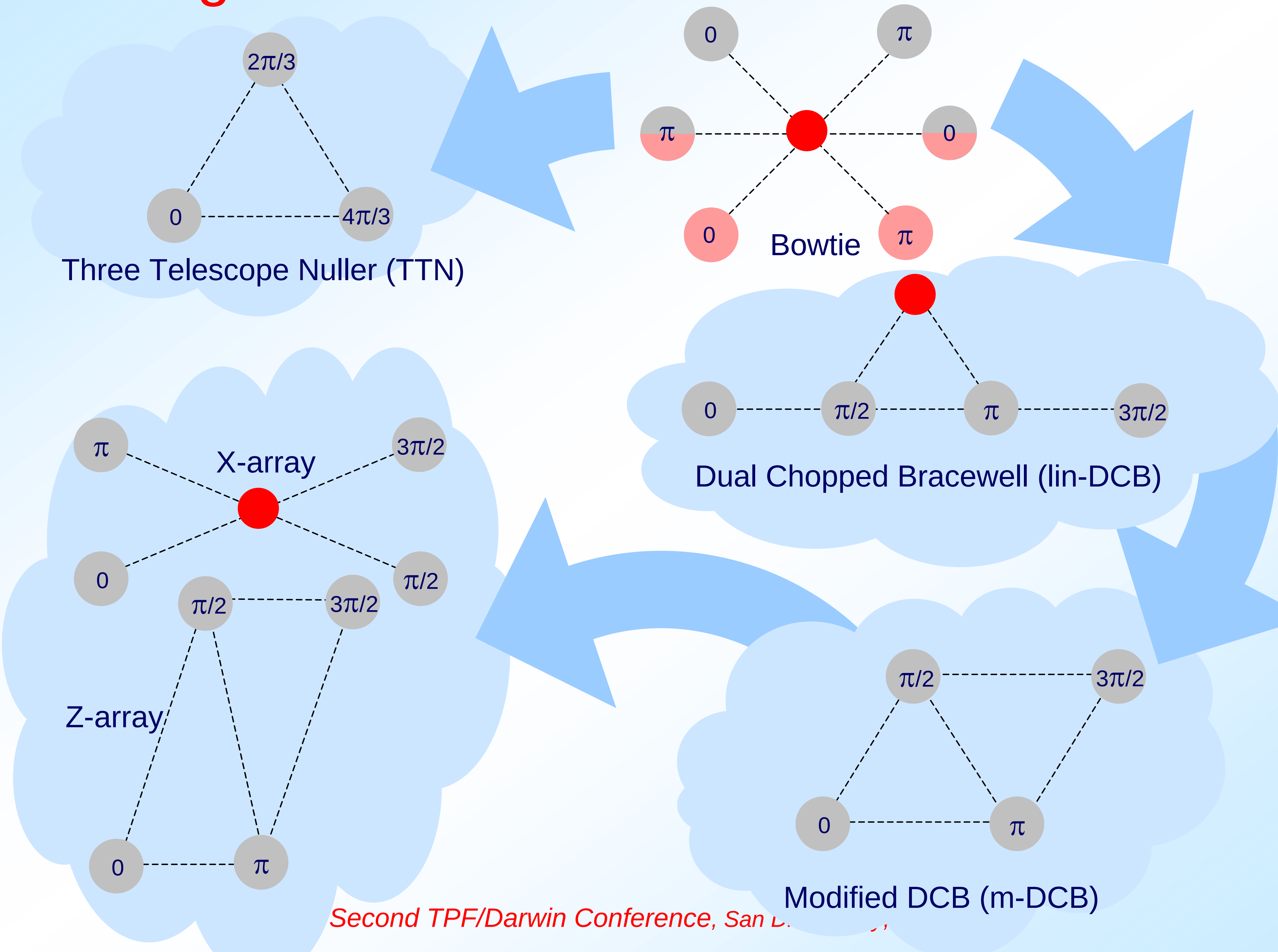
- **IR has less stringent requirements on technology – contrast & resolution**

- **IR spectroscopy allows characterization in a direct, unambiguous and simpler fashion**

- **IR Interferometry allows a much larger sample of objects to be surveyed for Earth-like planets – 150 (285) than visual coronography**

- **Space Interferometer provides heritage for next generation missions ➔ Which will depend on high spatial resolution imaging for a number of topics**

Configurations



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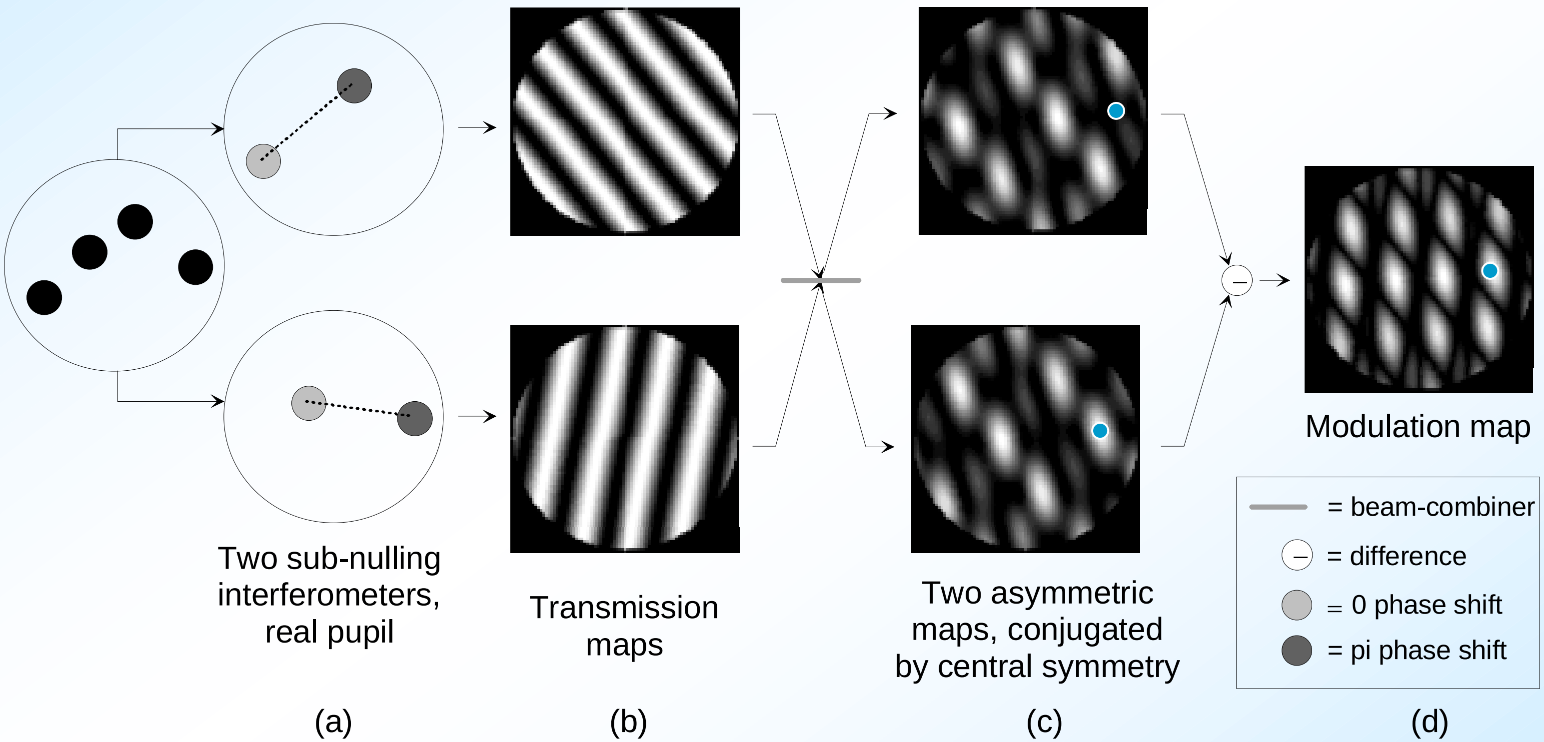
Internal Modulation

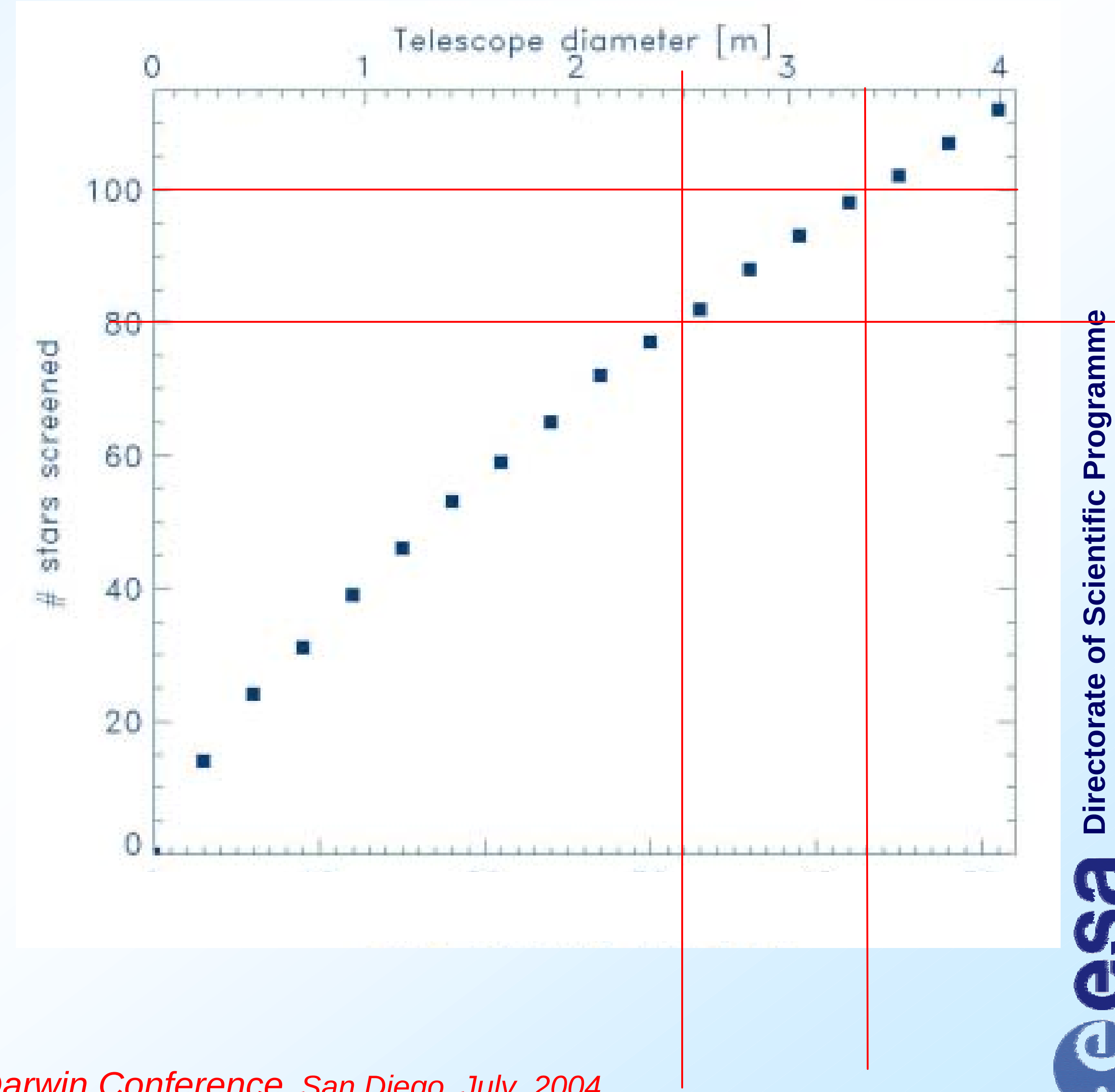
The double-Bracewell configuration with Internal modulation



Internal modulation → stellar leakage, zodi and exo-zodi light subtraction

Number of screened target stars, 4-element-array

Catalogue number of stars:	**285**
detection period [years]: **fraction spent on integration:**	**2** **80%**
# revisits:	**3**
detection SNR limit:	**5**
completeness limit: **(fraction of planets detected)**	**90%**
inner habitable zone [AU]: **outer habitable zone [AU]:**	**0.8** **1.7**
exo-zodiacal background: **(compared to solar system)**	**10**
planetary temperature [K]:	**265**
planetary radius [$R_\oplus$]:	**1**
instrumental throughput:	**0.1**
minimum tip-to-tip distance [m]:	**10**



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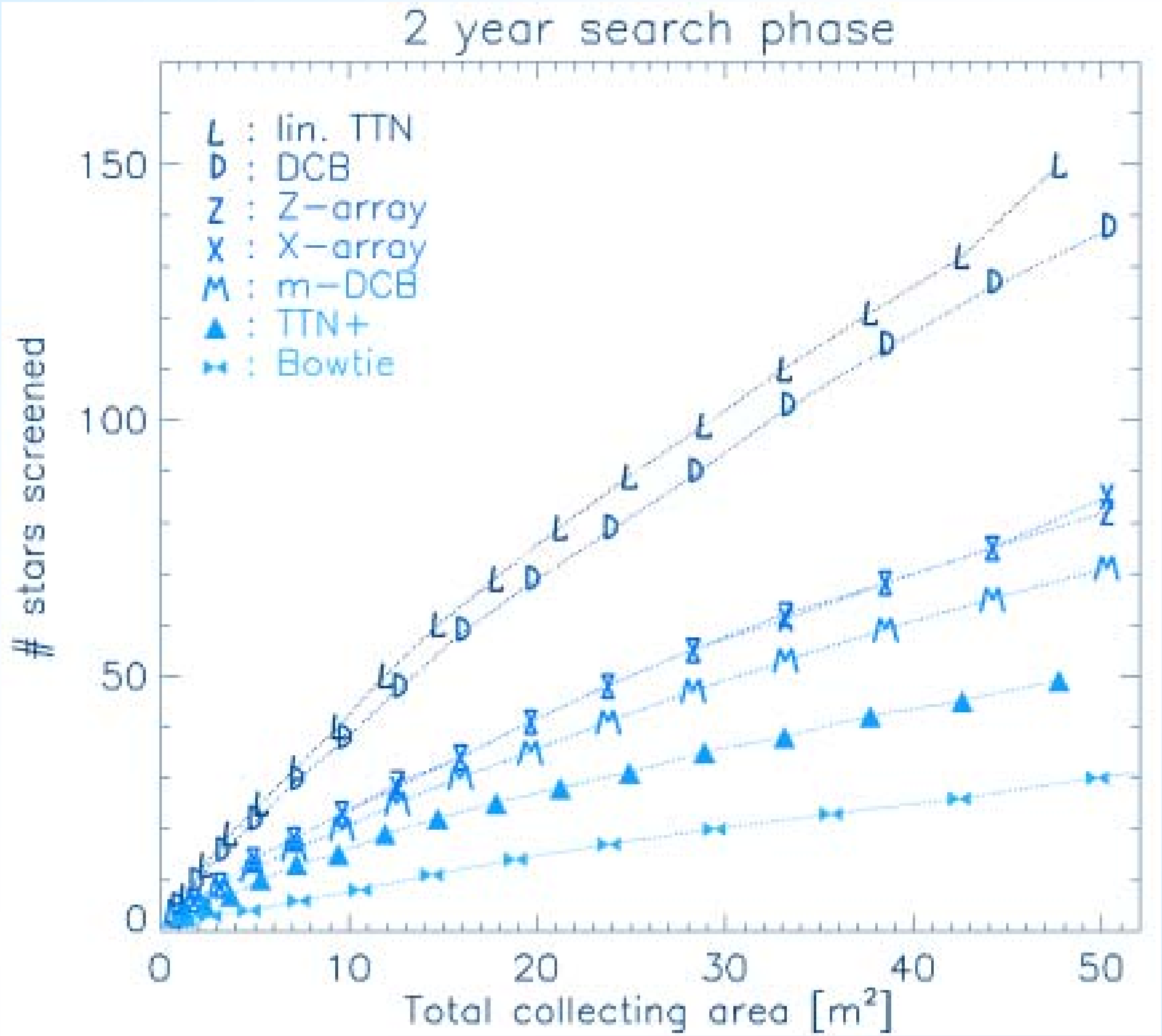
4 s/c trade-off



Second TPF/Darwin Conference, *San Diego, July, 2004*

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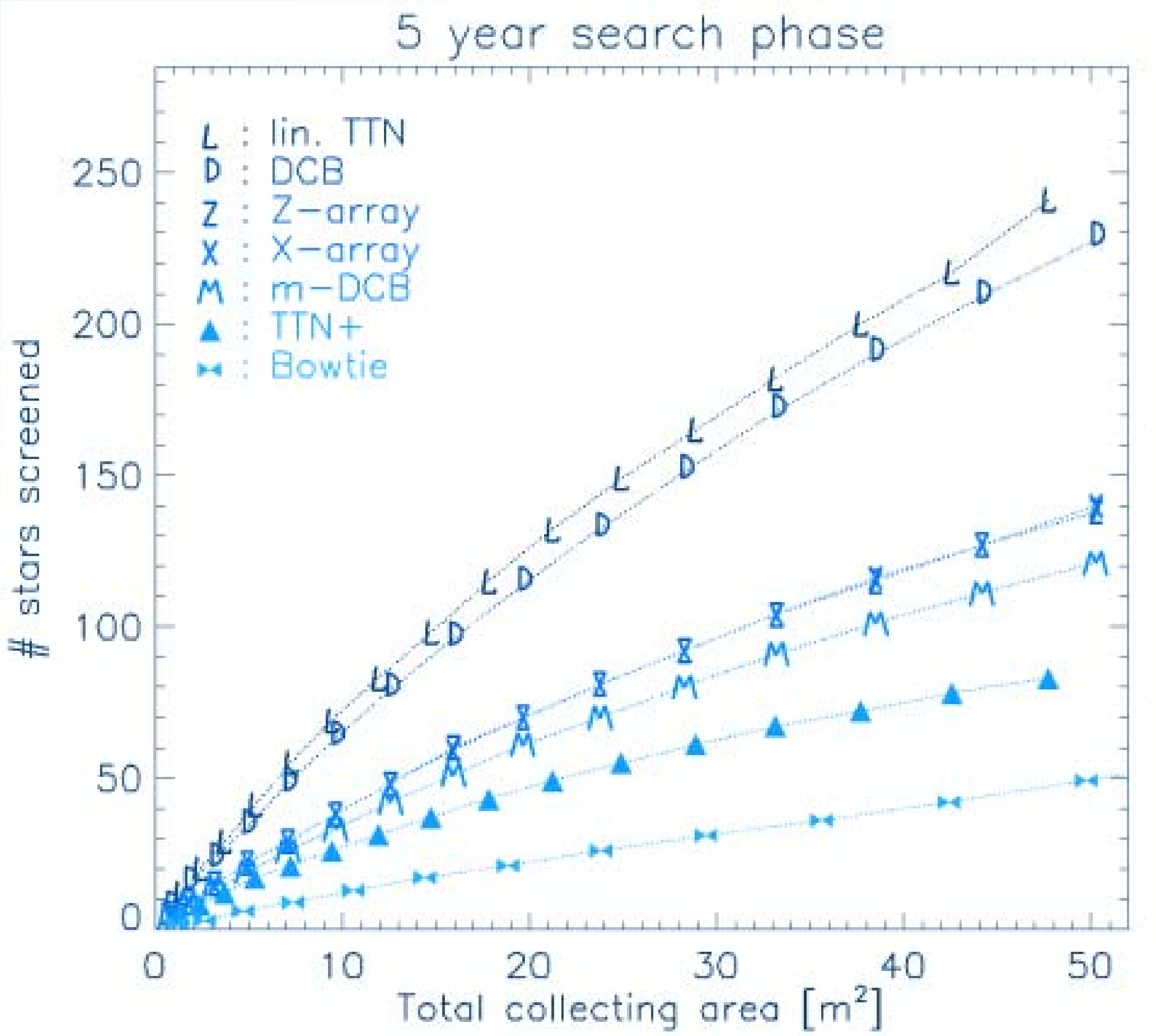

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Darwin

ESA has the objective to be flying Darwin in the middle of next decade

Cosmic Vision process on-going ➔ Masterplan ~ Nov 2004 – Feb 2005 (SPC)

➔ Darwin must aim towards flight readiness in 2015 ➔ Precursor activities

GENIE – Optical ground based demonstration of nulling (Technology and measurements of exo-zodi)

Free flying mission or ground based demonstration

New Darwin baseline – October 2004

Soyuz * 2 to L2

3 or 4 telescopes based on Herschel ~ 3.2m mirrors polished to normal optical quality

1 or 2 beam combiners

Can do all stars to 25pc + number of M-dwarfs in nominal mission

ESA only or ESA led mission

Launch 2015

Tight schedule → New approach to pre-cursor activities

Study phase Now – 2006 → Project

Development phase ~3 years

Phase C/D → 2009 – 2015 → Launch

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Darwin-GENIE

background and objectives

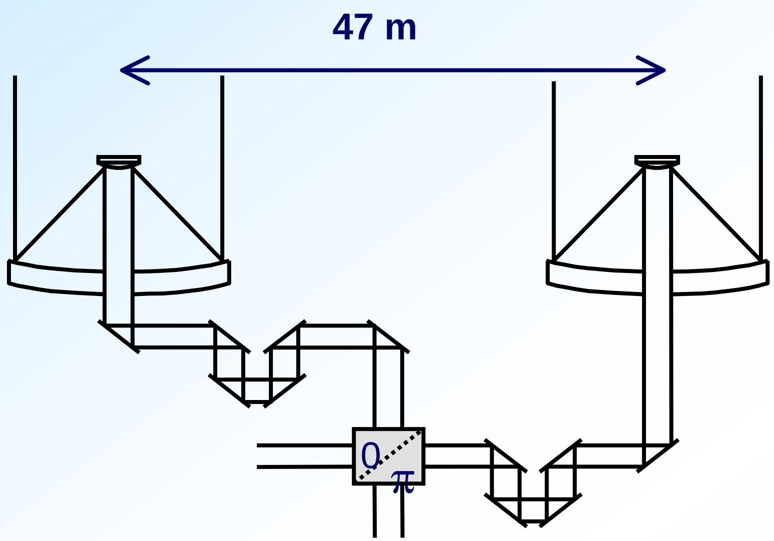
Motivations:

• to experiment nulling interferometry and provide European Industry with 1st experience
• to benefit from ESO VLTI facility and ESO experience in interferometry
• to test Darwin technology in an integrated and operational system

Objectives:

1. **Nulling technology demonstrator**
2. **Preparation of Darwin program**
3. **Low-mass companions (planets)**
4. **General user instrument**

Nulling technology demonstrator



Major Genie test of Darwin functions:

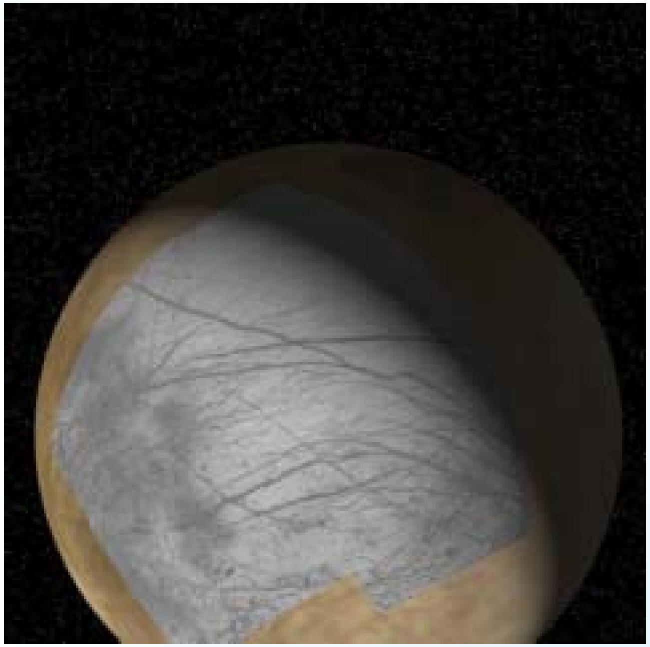
- Amplitude control loops
- High accuracy OPD control loop
- Dispersion control
- Polarisation compensation
- Background subtraction
- Internal modulation

Preparation of Darwin program

Measurement of all potential Darwin target stars in southern hemisphere to characterize level of exo-zodi

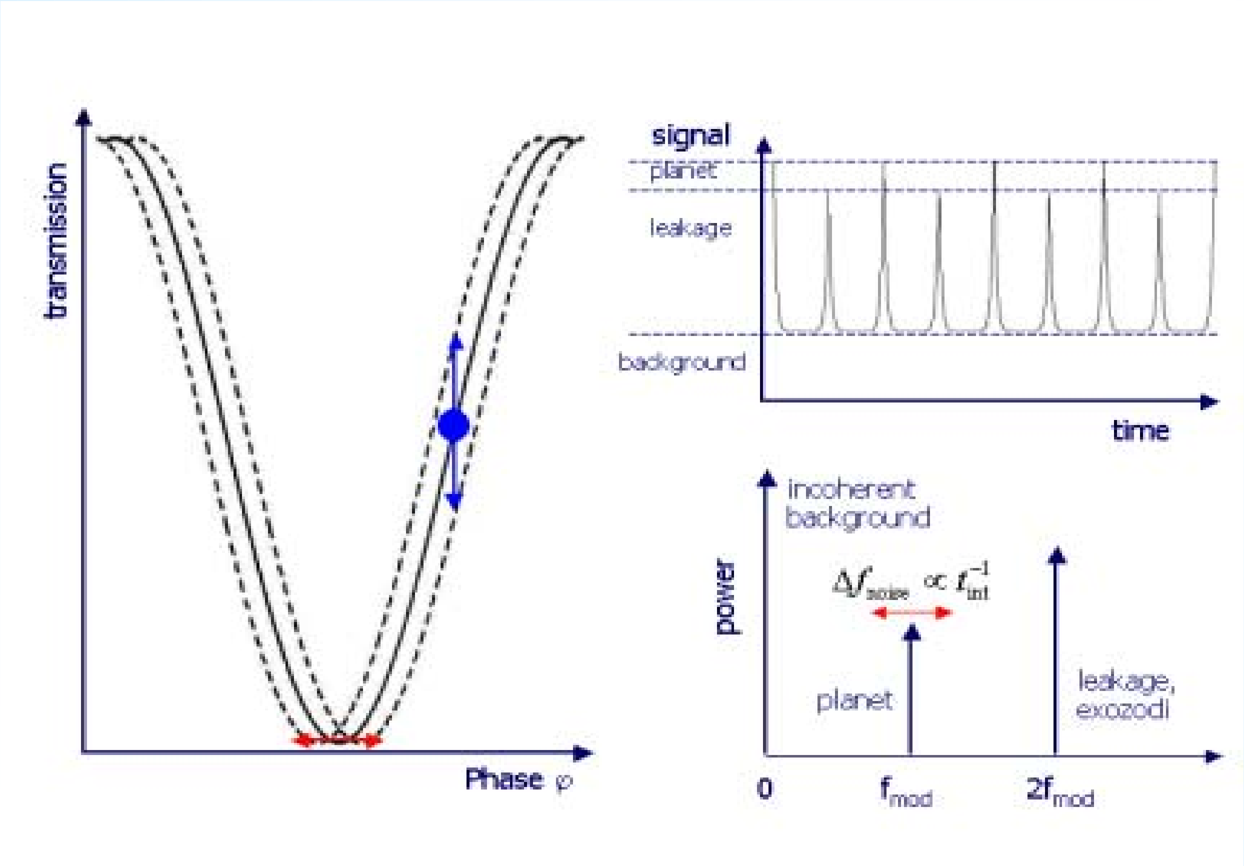
Determination of if large mass objects exist in close orbits at high values of inclination

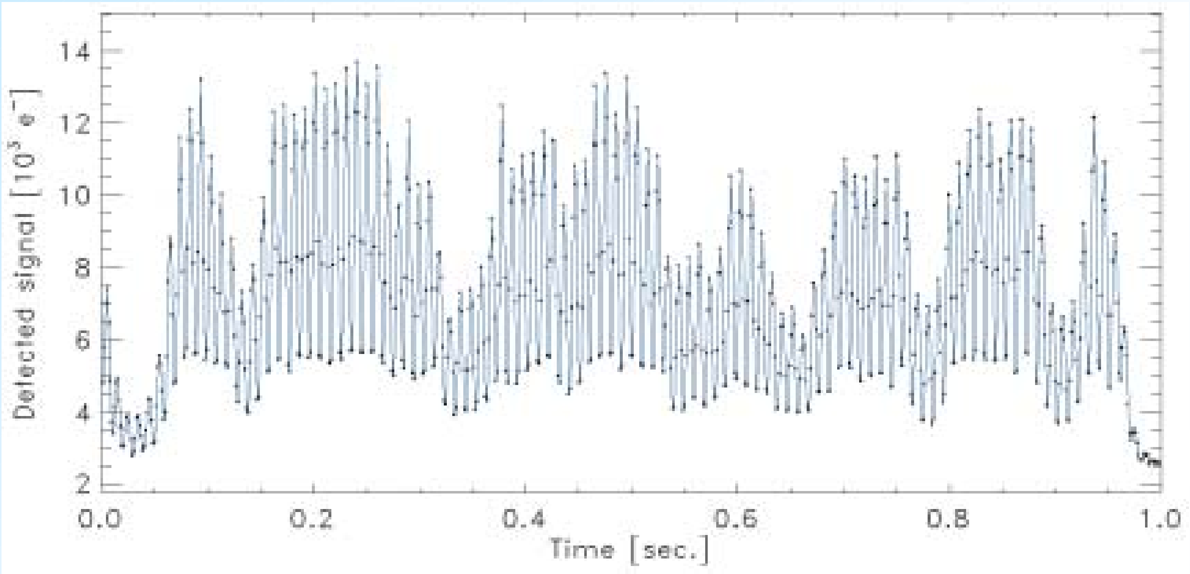
Significant observing time on AT's and UT's required

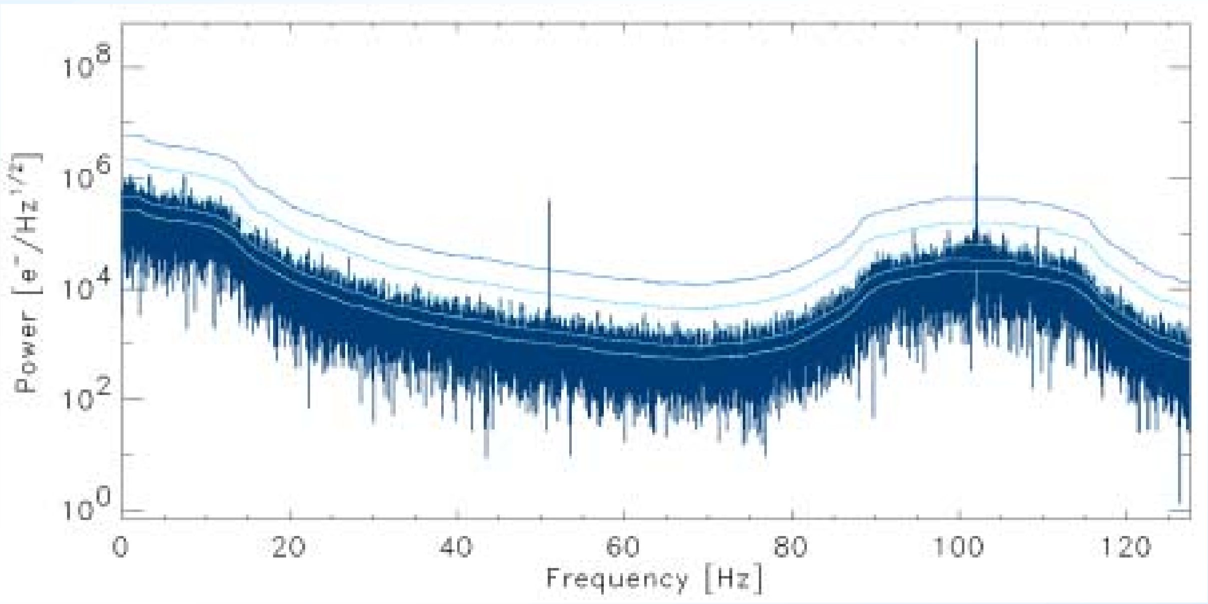


Detection and study of exoplanets!

OPD Modulation







a. One second of simulated output. The modulation frequency is 51 Hz, which is faster than the fluctuations in the signal due to variations in leakage and coupling. b. The Fourier transform of the full observation, clearly revealing the peak of the planetary signal, and the leakage at twice the modulation frequency. The solid lines indicate from bottom to top the location of, respectively, the local average(baseline) of the signal, 1, 3, 10 and 30 standard deviations above average.

FF Demo

Flight Demo:

- Need >= 2 S/C
- Need representative FF system
- Must be in same or equivalent environment (L2)

Pros:

- Risk reduction
- Experience gain
- Possibly opportunity for some science

Cons:

- High cost: need very solid justification
- Not the full formation (Darwin)
- No representative dynamics (not the same S/C)
- Programmatic constraints (FF Demo schedule)

FF Ground Demo

Ground Demo of FF:

- Good and reliable ground tools available
- Full SW simulations with high fidelity
- Demo of some critical elements in HW facilities
    - Sensors, actuators
    - Feedback loops, etc
- Considerably lower cost than flight demo
- Examples of ground verification:
    - ATV docks to ISS on maiden flight (N.B. man-rated)
    - JWST mirror

European Free-flyer demonstrator in National program for launch in 2010/11

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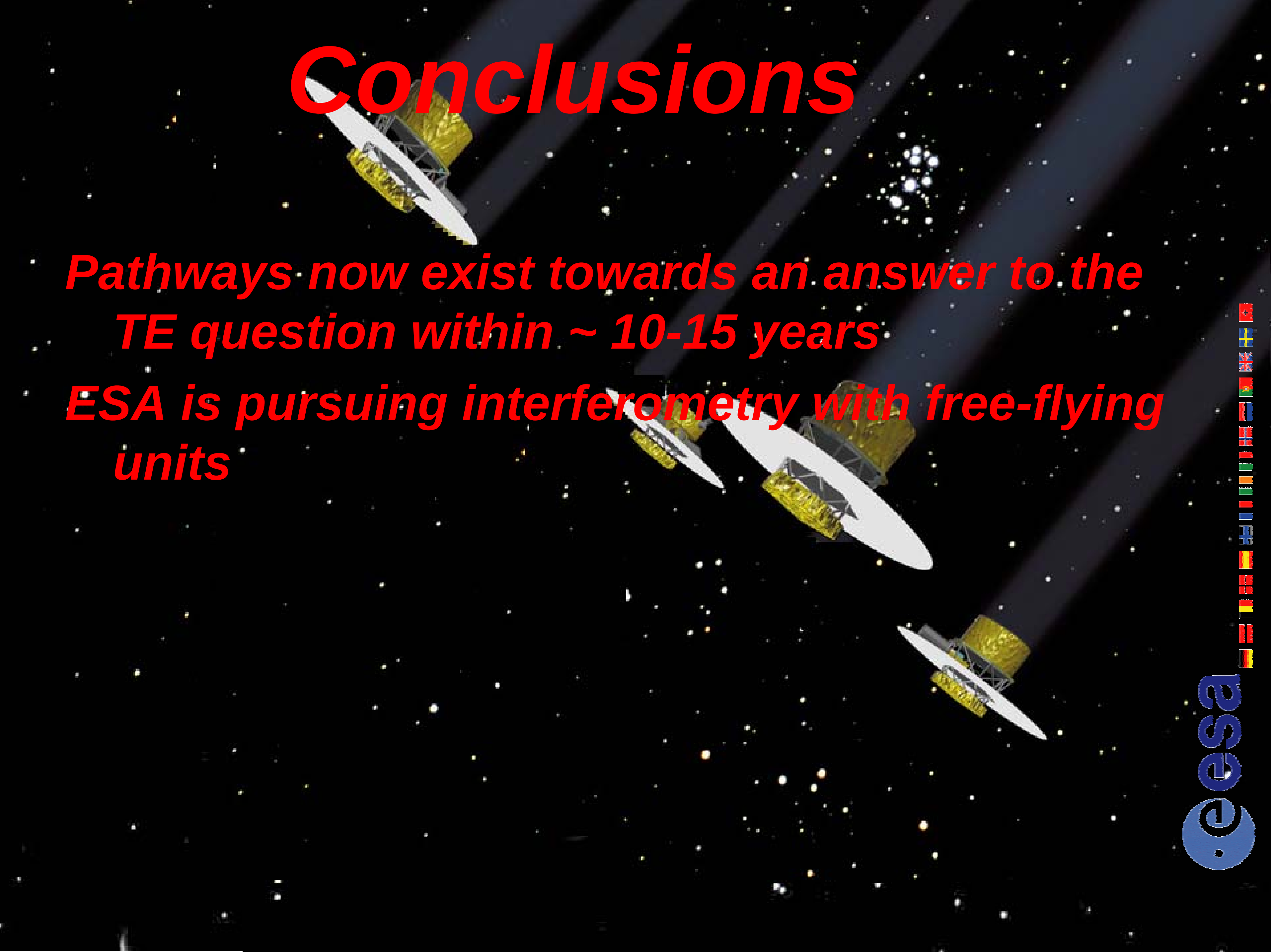
The Heritage of Darwin

A. New science require high spatial resolution – at all λ
B. Coronographs can only be just so big
C. Very large interferometers will have to be built
D. Terrestrial Planet Imager, Life finder

E. Large IR interferometer can reach << 1 μJy < 1h

F. 25-50 resolution elements across nearby planetary surfaces



Conclusions

- *Pathways now exist towards an answer to the TE question within ~ 10-15 years*
- *ESA is pursuing interferometry with free-flying units*